Title

System for Accurately Repositioning Imaging Devices

RELATED APPLICATIONS

[1] Priority is claimed from Provisional application 60/461,952 filed 04/08/2003.

BACKGROUND

[2] Time-lapse images are used in a variety of applications including determining seed-lot growth rates, analyzing mechanical wear or corrosion, generating calibration signatures for oil exploration, and generating special effects for the advertising and motion picture industries.

[3] High-quality time-lapse image sequences generation requires accurate repositioning of an imaging device relative to the subject of interest. Current techniques for repositioning imaging devices require complex and expensive hardware.

[4] Mathematical formulae for extracting the pose (camera center and orientation relative to the scene of interest) of an imaging device are known. Multiple View Geometry In Computer Vision by Richard Hartley and Andrew Zisserman, Cambridge University Press 2000 presents a full treatment of the required math. Similar mathematical techniques are used for blending images into panoramas or steadying an image subject to camera jitter.

[5] Current approaches for time lapse imagery, however, require highly accurate coordinate measurement devices to determine camera location relative to target. Photogrammetry techniques have been used to account for changes in position as between two images, machine vision has been used to periodically locate an image capture device but requires dedicated hardware not easily adapted to other applications (US 5,863,984). Real time image warping has been used to correct for camera inaccuracies in camera position, yet this solution is not useful for images taken at different

times (US 6,396,961). Image alignment techniques do not address acquisition or alignment of future images (US 6,173,087).

[6] What is needed is a low cost, easy to use system for generating and displaying high quality time-lapse sequences. Also needed is a time-lapse image generation system that is adaptable to various imaging applications.

SUMMARY OF THE INVENTION

[7] The invention provides a simple method for accurately repositioning an imaging device using feedback to the imaging device operator coupled with an apparatus for automatically adjusting the position of the imaging device.. The present invention provides a method and system, including a unique apparatus, that enables an imaging device to be precisely repositioned relative to a subject of interest. The invention provides a method and system for easily and accurately reposition an imaging device and to generate high-quality time-lapse image sequences, eliminating the need for expensive positioning hardware or dedicated imaging.

[8] The invention provides a system of hardware and software to acquire and compare a new image with a reference image of the scene of interest. Photogrammetric techniques are used to determine the position of the imaging device relative to the position of the device used to capture the reference image. The difference in camera centers between the reference image and the newly acquired image is calculated and used to reposition the imaging device (the term camera center is a mathematical concept used in photogrammetry, camera centers can be calculated for any type of imaging device.). This process is repeated until the error between the reference image and the new image is below an acceptable threshold.

[9] The imaging system to reposition an image capture device in a position relative to a subject of interest as that of a reference image of the subject of interest, includes an image capture device; a position apparatus on which the image capture device is mounted and which precisely

orients the image capture device relative to a subject of interest; a reference image of the subject of interest; a computational device coupled to the position apparatus, such computational device capable of receiving images from the image capture device and of receiving the reference image, performing a comparison, and communicating position adjustments to reposition the image capture device.

BRIEF DESCRIPTION OF THE DRAWINGS

[10] Fig. 1 depicts the components of a system for accurately repositioning an imaging device according to an embodiment of the present invention.

[11] Fig. 2 is a generalized flowchart of the various function modules of the system for accurately repositioning an imaging device according to an embodiment of the present invention.

[12] Fig. 3 depicts further details of the initialization process, including an example reference image. The reference image is analyzed in order to extract data that will be used later to reposition the imaging device.

[13] Fig. 4 depicts further details on the repositioning process, including an example of a new image and the computation of the offset in camera centers.

[14] Fig. 5 illustrates the use of the repositioning apparatus to move the imaging device to the new position computed in the process illustrated in Fig. 4.

DETAILED DESCRIPTION

[15] The invention provides a system, method and apparatus for accurately repositioning imaging devices such as film-based cameras, digital cameras, video cameras, film-based projectors or video projectors. The inventive method and system employs hardware and software components that allow a user to accurately reposition an imaging device over a long-term period of minutes, hours, weeks, months or years. Accurate positioning of an imaging device is necessary for generating high quality time-lapse image sequences for a variety of applications.

[16] Fig. 1 depicts the inventive system for accurately repositioning imaging devices. The imaging device **100** is mounted on a positioning apparatus **108**, which is controllable and the control of which may be automated,(said apparatus 108 is also referred to herein as the automatic repositioning apparatus) which in turn is mounted on a stable platform **110**. While the automatic repositioning device 108 may be incorporated into the image capture device, or be coupled to the imaging device in alternate configurations, including remote or robotic control, the system discussed here contemplates a distinct apparatus. The imaging device **100** captures a new image of the scene of interest **102,** which is input to the computational device **106** through the bi-directional path **114**. The reference image **104** is also input to the computational device **106** through path **112**. The computational device **106** determines the difference in camera pose, and transmits this information to the automatic repositioning apparatus **108** through the bi-directional path **116**. A user interface **118** indicates the amount and direction of movement required to accurately reposition the imaging device relative to the scene of interest **102**. The automatic repositioning apparatus **108** accurately repositions the imaging device **100** if the required displacement is within the range of motion of the apparatus **108**. If the required displacement is outside the range of motion of the automatic repositioning apparatus **108,** then the user interface **118** instructs the operator to move the stable platform **110** the required distance in the required directions.

[17] Fig. 2 is a generalized flowchart for the various function modules comprising one embodiment of the present invention. The initialization process **200** is used to prepare an image of the scene of interest for use as a reference image in the repositioning process. The initialization process includes steps **202, 204, 206,** and **208**. The first step of the initialization process is **202**; acquire a reference image of the scene of interest. This image can be an historic photograph, or an image captured by a film-based or digital camera. The preferred embodiment uses a digital image from the same imaging device that will be repositioned in later steps of the process. Step **204** is the

identification of points in the reference image that are likely to remain stable over the timeframe of interest. Various algorithms exist to automatically extract features such as contours, edges and corners from an image. The preferred embodiment uses a combination of automatic feature extraction and guidance from the user to identify a number of fixed points in the reference image. In step **206**, a three dimensional model of the object represented by the fixed points is generated. This three dimensional (3D) model can be generated directly by measurement of points in the scene of interest, or it can be extracted from multiple views of the scene of interest taken from known camera centers. In step **208**, the reference image, the location of the fixed points and the 3D model of the fixed points are stored for use later in the repositioning process.

[18] The dashed line **210** in Fig. 2 indicates that there is a time-lapse of undetermined length between the execution of the initialization process **200** and the repositioning process that begins with step **214**. Step **216** is to acquire a new image of the scene of interest. In the preferred embodiment, the same imaging device used to generate the reference image generates the new image. In step **218** fixed points are identified in the reference image using techniques similar to those described for step **204**. In steps **220** and **222**, the fixed points identified in step **218** are mapped onto the fixed points identified in step **204** and the offset in camera center between the new image and the reference image is computed. Algorithms for computing the offset in camera center between two images and a full treatment of the mathematics required are in <u>Multiple View Geometry In Computer Vision</u> by Richard Hartley and Andrew Zisserman, Cambridge University Press 2000. The inventive method employs well-known mathematical formulae for extracting the pose (camera center and orientation relative to the scene of interest) of an imaging device.

[19] In step **224**, the computed offset in camera center between the new image and the reference image is analyzed. If the offset is small enough that further repositioning of the imaging device will not improve the quality of the time-lapse sequence, then the process exits through step

226. If the offset is large enough to decrease the quality of the time-lapse sequence, then the imaging device is moved by the computed offset (step **228**) and the repositioning process in repeated through feedback path **230**.

[20] Fig. 3 is a generalized flowchart of the method of operation of one embodiment of the initialization process **200** of the present invention. **302** is a conceptual illustration of a reference image acquired in step **202**. The results of the process for identifying fixed points in the reference image (step **204** from Fig. 2) are shown conceptually in image 304. The circumscribed crosses collectively identified as **306** indicate the locations of the fixed points in the reference image. An arbitrary fixed point, **308**, was chosen as the origin of the real-world coordinate system for the 3D model of the fixed points. The 3D model of the fixed points consisting of X, Y, and Z coordinates is shown in tabular form in **310**. The coordinates of the arbitrary origin (the point identified as **308**) are shown collectively as **312**.

[21] Fig. 4 is a generalized flowchart of a portion of the process for repositioning an imaging device in one embodiment of the present invention. **402** is a conceptual illustration of a new image of the scene of interest with fixed points identified. The circumscribed crosses collectively identified as **404** indicate the locations of the fixed points in the new image. The arrows collectively identified as **408** in conceptual illustration **406** indicate the mapping of the fixed points in the new image into the fixed points in the reference image. A table of the computed offset in camera center between the new image and the reference image are shown in **401**. These offsets can be easily computed using algorithms explained in Multiple View Geometry by Hartley and Zisserman.

[22] Fig. 5 is a conceptual illustration of the movement of the imaging device by the computed offset in camera centers. The movement of the imaging device has six degrees of freedom, consisting of translation along three orthogonal axes and rotation around those same

orthogonal axes. These translations are shown conceptually in Fig 5 as translation along the X, Y, and Z axis, identified as **502**, **506** and **510** respectively. The rotations are shown conceptually in Fig. 5 as Pitch, Yaw, and Roll, identified as **504**, **508**, and **512** respectively. The coordinate directions are chosen to be consistent with common practice in imaging applications. The user interface **118** in Fig. 5 indicates that the imaging device **100** should be moved 3.96 units in the negative Z direction. This is consistent with the offset in camera center computed in step **222** and shown in table **410** of Fig. 4. If the movement required in **228** is too large to be done automatically by apparatus **108**, then the user interface **118** will indicate that the operator needs to move the stable platform **110** by a specified amount in the X, Y, and Z directions and begin the repositioning process again with step **216**. If the computed offset in camera center is within the range of the automatic repositioning apparatus **108**, then the imaging device **100** will be repositioned automatically and a new image will be acquired. The repositioning process stops when the displacements between the fixed points in the new image and the reference image are within the tolerance required for the time-lapse sequence being generated.

[23] The inventive method and system and the apparatus used therein can be applied to, but is not limited to, applications such as: revealing hidden detail in commercial and residential construction; documenting changes that occur during time-frames of arbitrary length; revealing sun / shade patterns over the course of a day or a year; producing special effects for the movie and advertising industry; documenting cityscapes as they change over time; analyzing plant growth over days and years; inferring weather related effects from leaf growth comparisons over multiple years; recording natural erosion or wear patterns; creating new art-forms with time as an element; displaying proposed changes in the design of interior spaces.